EVALUATION OF INTRAMEDULLARY NAILING IN LOW-VELOCITY GUNSHOT WOUNDS OF THE RADIUS AND ULNA

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University of Witwatersrand, Johannesburg

in part fulfillment of the requirements for

the degree of Master of Medicine in the branch of Orthopaedic Surgery

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DECLARATION

I, Bradley Rael Gelbart declare that this Research Report is my own work. It is being submitted for Master of Medicine (in the branch of Orthopaedic Surgery) to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

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Bradley Rael Gelbart

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PRESENTATIONS

Some of the data was presented in the form of an oral presentation entitled:

Gelbart BR, Aden AA, Barrow AD. Evaluation of intramedullary nailing for low velocity gunshot wounds of the Forearm – A Provisional report. Paper 7, 53rd South African Orthopaedic Association Congress, 3-7 September 2007; Johannesburg, South Africa

ABSTRACT

Intramedullary nail insertion into a fractured bone allows stabilisation of the fracture with minimal intervention through the zone of injured tissue.

This study aimed to assess whether intramedullary nailing of the forearm bones (radius and/or ulna) is a safe and effective form of management of these often complex fractures. A prospective case series was followed from presentation to fracture union.

Between April 2006 and February 2008, 21 patients were enrolled in the study. The fracture union rate was high and complication rate was low. There was no increased risk of sepsis. The use of intramedullary nailing for diaphyseal fractures was successful but metaphyseal fractures, particularly with shortening, may be problematic.

The use of intramedullary nailing for radius/ulna fractures is safe and effective, however the widespread use of this technique may be limited by the cost of the implant.

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NOMECLATURE

BMP – Bone Morphogenic Protein

DRUJ – Distal radio-ulnar joint

GSW – Gunshot wound

EPL – Extensor Pollicis Longus

FGF – Fibroblast growth factors

IM – Intramedullary

ORIF – Open reduction and internal fixation

TGF-β – Transforming Growth Factor Beta

PREFACE

South Africa is world renowned for the amount of trauma that presents to its hospitals and institutions. The spectrum of injury results from trauma sustained in everyday activities to high energy trauma with multiple system injuries, and sadly a large number of injuries secondary to interpersonal violence.

The easy availability of low-velocity firearms results in a high incidence of gunshot wounds. Firearms are responsible for the highest percentage of fatalities in the 24-54 year age group(1). South Africa has the third highest level of civilian related firearm mortality following Colombia and Venezuela(2). Since reporting of non-fatal gunshot injuries is not mandatory we can only extrapolate these above figures to suggest the prevalence of gunshot injuries in South Africa

The vast majority of research is published from First world centres where the prevalence of these unique injuries is far less common than in South Africa.

Although nothing to be proud of, we should be leading the world in the management of these injuries.

1. INTRODUCTION

The purpose of this study is to investigate if intramedullary nailing of low velocity gunshot fracture of the radius and/or ulna results in reliable fracture healing and is not harmful to the patient. The secondary evaluation includes the level of functional return achieved in these patients.

1.1 Definitions

1.1.1 Radius and Ulna

The radius and ulna are two separate bones which together form the forearm. The bones are held together by a fibrous interosseous membrane and articulate with each other proximally at the proximal radio-ulnar joint and distally at the distal radio-ulnar joint (DRUJ). This interaction allows for pronation and supination of the forearm/wrist/hand complex. Proximally the radius and ulna articulate with the humerus at the elbow joint. Movement across this joint produces flexion and extension at the elbow.
The distal ends of the radius and ulna articulate with the carpal bones to form the wrist joint. Movements at the wrist joint include flexion and extension and radial and ulnar deviation.

The bones themselves are comprised of proximal and distal cartilage covered articular surfaces. Moving towards the middle of the bone we then encounter the metaphysis which is comprised of cancellous bone and then the diaphysis – the shaft of the bone. The radial head is situated proximally and the ulna head is situated distally (Figure 1).

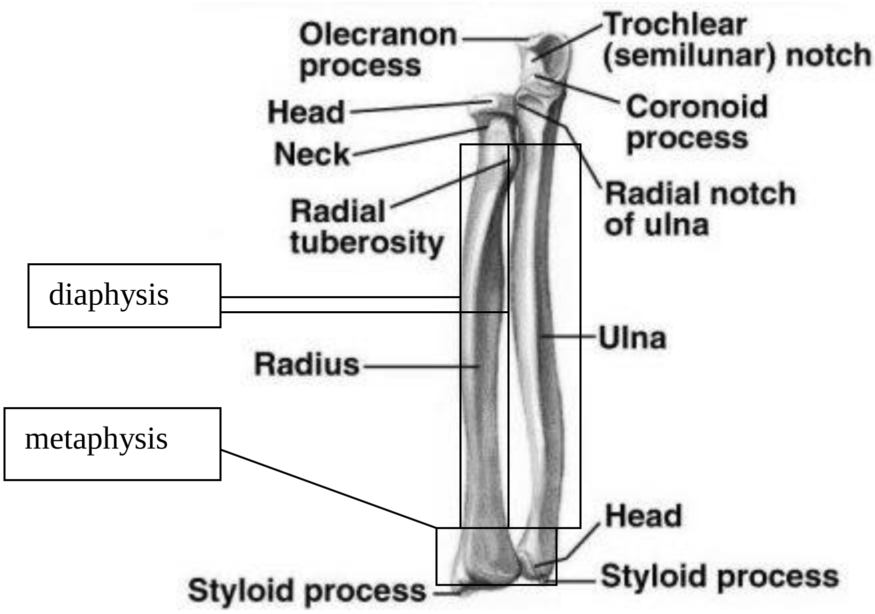

Figure 1

Reproduced with permission. http://www.daviddarling.info/encyclopedia/U/ulna.html

Edited by author.

1.1.2 Low velocity gunshot wound

A bullet is a projectile metal body launched from the barrel of the firearm.

Traditionally, firearms have been divided by the bullet speed into low velocity (< 2000feet/second = 600metres/second) and high velocity (> 2000feet/second = 600 meters/second)(3). The velocity obtained by the bullet is proportional to the amount of gases produced by the ignition of gunpowder and the length of the barrel of the gun. The longer the barrel the more time the gases spend confined within the barrel and the greater the time for acceleration of the bullet.

However, when considering the injury to the patient caused by the bullet, it may be more appropriate to consider the kinetic energy of the bullet. Since the injury caused is due to transfer of energy from the bullet to the body, the higher the energy transfer the more devastating the injury.

The kinetic energy of the bullet at impact = ½ mass x velocity^2

According to the above equation it is clear that the velocity of the bullet is much more influential on the kinetic energy than the mass. It is therefore tempting to use the terms low velocity gunshot wound and low-energy gunshot wound interchangeably. Numerous studies have been aptly summarized by Bartlett (3) who shows that there are multiple factors involved in producing the final injury seen by the physician. These factors are not limited to the muzzle velocity of the bullet.

This study primarily reviews the outcome of civilian patients who sustained gunshot wounds resulting in comminuted fractures. While there is certainly much to dispute over the exact energy transfer, the use of Gugala and Lindsey's (4) classification (appendix B) of civilian gunshot wounds has allowed some standardization of the enrolled patients.

1.1.3 Intramedullary nail/rod (Figure 2)

Intramedullary (IM) fixation of fractures is obtained by placing a metallic, usually stainless steel or titanium, rod into the medullary cavity of the bone. The terms IM rod and IM nail are used interchangeably.

Resistance to bending forces at the fracture site is provided by the stiffness of the material and the long interface between the rod and the cortex of the bone. Rotational forces are countered by one of a number of methods. The most common method of counteracting rotational forces is by the use of an interlocking screw. This screw engages the bone cortex on either side of the nail and passes through a hole in the nail. Other methods of obtaining rotational stability include interference between the nail and the cortex in the diaphysis of the bone e.g. expanding nails, or expanding flanges at the end of the nail, again relying on friction for stability.

Recently designed intramedullary rods for the radius and ulna are contoured to meet the natural bends of the bone, and widen at the end opposite to insertion, to allow purchase into the soft metaphyseal bone. The ability to lock the nail with a screw at the insertion end and gain metaphyseal purchase at the opposite end provides rotational stability. These rods are indicated for fractures of both radius and ulna and severely comminuted fractures, amongst other indications (5).

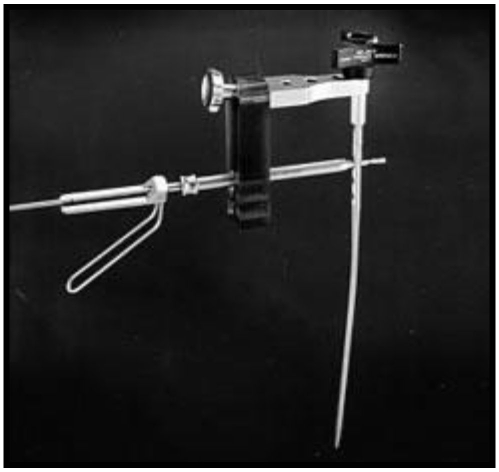

Figure 2: Ulna rod and locking guide system

1.2 Background

1.2.1 Bone Healing

Bone is the major structural tissue in the human body. It consists of cells and extracellular matrix. One of the functions of bone is to provide support and attachment of other tissues to allow for movement. Loss of integrity of bone results in decreased function. A fracture is a break in continuity of bone, and in order to restore that continuity bone has the ability to heal or unite.

There are 2 main types of bone healing (6):

a) Primary bone healing

   This type of healing occurs in anatomically reduced, stably fixed fractures. Healing occurs by direct osteonal penetration with no external bridging callus.

b) Secondary bone healing

   If bone is not rigidly stabilised and there is motion at the fracture site then bone heals by callus formation.

The sequence of bone fracture healing consists of

i) Extravasation of blood at the fracture site and haematoma formation.

ii) Inflammation and cellular proliferation – acute inflammatory cells proliferate and fragment ends are surrounded by cellular tissue. Capillaries grow into the area. This tissue is rich in inductive proteins.

iii) Callus formation – the proliferating cells (ii above) are potentially chondrogenic and osteogenic. These form islands of immature bone and cartilage. This mass becomes more densely mineralized and movement at the fracture site decreases. This process is driven by inductive proteins such as fibroblast growth factors (FGF), transforming growth factor beta (TGF-β) and bone morphogenic proteins (BMP). At the end of this stage the fracture is said to have "united".

iv) Consolidation – callus (woven bone) is transformed into lamellar bone. Over the next few months this bone is strengthened by the continued laying down of new matrix by osteoblasts.

v) Remodelling – The fracture site and surrounding bone are reshaped according to the prevailing stress on the bone.

1.2.1.1 Problems with bone healing

1.2.1.1.1 Delayed union

Delayed union is defined as a prolonged time for the fracture to unite. This term is usually reserved for fractures that have not achieved union by the expected time but eventually go on to unite. The expected time for union in forearm fractures is 6-8 weeks in adults.

1.2.1.1.2 Non union

Non-union is defined as failure to show any progressive change in radiographic appearance for at least 3 months after the period of time during which normal fracture union was expected to take place (6). This is generally accepted as 6 months from time of injury.

Non-union is due to failure of biology (high energy with devascularisation), failure of the host (nicotine, vascular disease, other comorbidities), failure of mechanics (improper stabilisation) or treatment failure (iatrogenic devascularisation). Sepsis should always be considered in any non-union.

1.2.1.1.3 Malunion

Union of the fractured bone in a position other than anatomically correct is defined as malunion. This may occur in any of the three planes sagittal, coronal and axial. Depending on the bone involved the amount of deviation from normal will have variable effects. It is well known that slight inaccuracies in reduction of the radius and ulna may have profound mechanical effects.

1.2.2 Fracture pattern

Bone tends to fracture in a predictable pattern following an injury that exceeds the failure load of the bone. Lower energy injuries tend to produce linear fractures. These may be transverse, oblique or spiral. This produces two conforming ends of bone that are either undisplaced, or if displaced, one is able to confidently reduce the bone to its original configuration.

Communition refers to a fracture where there are more than two bone ends and generally occurs with higher energy injuries. The term is broad as it may be used for a transverse fracture with a small third fragment, or it may be used for a bone shattered into dozens of pieces following a gunshot wound. The more comminuted the fracture site the more difficult to obtain anatomical reduction, and more extensive the damage to the surrounding soft tissues. Comminution also makes the fracture less stable and therefore more likely to displace, and may also delay healing[1].(Figure 3)

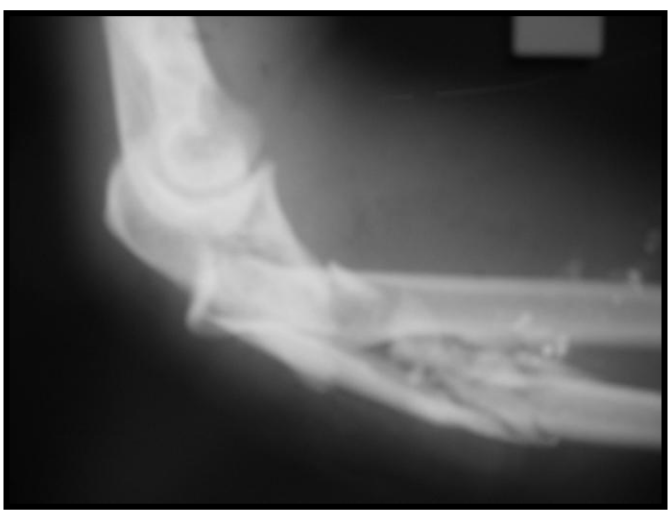

Figure 3: Comminuted fracture of the ulna due to a gunshot injury – Monteggia fracture

[1] Comminution and displacement of either the proximal or distal radio-ulnar joints was seen. There was a proximal radio-ulnar joint dislocation, as in this figure, seen in one patient. Three patients had DRUJ dislocation. These are significant as they indicated damage to the interosseous membrane and therefore a more unstable injury. Care must be taken to ensure absolutely perfect rod length when reducing.

1.2.3 Fracture fixation

1.2.3.1 Absolute stability

A linear fracture can be reduced anatomically and rigidly stabilised by means of compression plating. This brings the two bone ends into contact and does not allow movement between them. The fracture unites by primary bone healing and remodelling with no callus formation.

1.2.3.2 Relative Stability

Comminuted fractures are more difficult to reduce anatomically. The goal in the management of these injuries is to restore, to the surgeon's best ability, the mechanical and anatomical axes[2] of the bone. Methods of fixation include intramedullary fixation, bridge plating, and external fixators.

The key concept is that the fixation should provide enough stability to allow the bones to unite but allow enough micromotion to stimulate new bone formation.

This fixation should be obtained with as little damage to the already compromised surrounding soft tissues as possible. This is a benefit of these methods of fixation.

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[2] Anatomical reduction of fracture – aligning the fractured ends of bone to their exact anatomical position prior to fracture

Mechanical alignment - in some instances the fracture ends cannot be approximated perfectly due to too small or missing fragments – the goal is to then ensure the two joint surfaces are aligned in the correct planes to ensure normal joint function. The defect then will ideally fill with bone while healing.

1.2.4 Open Fractures

1.2.4.1 Classification

An open or compound fracture is defined as any fracture where there is communication between the bone and outside environment. This communication may vary from a small puncture wound to a large degloving injury with vascular injury. These fractures have been classified by Gustilo and Anderson (7) and subsequently further modified and updated by Gustilo and others (8, 9).

Fractures associated with gunshot wounds however are not considered in these classifications. These injuries have been recently classified by Gugala et al. (4).

1.2.4.2 Management

The principle of management of open fractures is complete debridement of the soft tissue tract between the bone ends and skin as well as debridement of the bone ends. The fracture is then stabilised either definitively or temporarily depending on the amount of contamination of the soft tissues. The level of contamination is usually proportional to the grade of the injury.

1.2.5 Current recommendations for gunshot related fracture management

1.2.5.1 Soft tissue management

Due to the different mechanism of injury of the soft tissues and bone in gunshot wounds, it has been difficult to correlate the amount of contamination of the fracture site with the size of the wound. This is due to factors including:

- Whether the bullet itself is sterile?
- Did the bullet pass through clothing or gastrointestinal tract?
- Did the negative pressure created by the bullet suck skin commensals into the fracture site?

The general consensus on the management of low-velocity gunshot wounds is that they should receive local irrigation with or without debridement and then 24 hours IV antibiotics as prophylaxis, although this has been questioned (10-16).

1.2.5.2. Fracture management

Management of gunshot fractures was initially non-operative as the concerns about sepsis predominated. Currently, non-operative management, when indicated, has shown equivocal results to operative fixation. This is particularly evident in the humerus (17, 18). However, some bones heal better if they are stabilised internally. If required, the surgery was initially performed as a delayed procedure (16, 19). More recently, superior results in the management of femur fractures was obtained with early intramedullary nailing, with a very low complication rate (20, 21). This has promoted the thought that early internal fixation of gunshot associated fractures is safe.

1.2.6 Complications of gunshot related fractures of the forearm

Gunshot related fractures are prone to the same types of complications as fractures caused by other trauma. These include delayed union, non-union and infection. Particularly important in the forearm is the implications of malunion. This results in limited function of the forearm and potentially the hand.

1.3 Research questions

1.3.1 Is intramedullary nailing of the radius and/or ulna after low-velocity gunshot injury safe? This is evaluated regarding implant design and function**,** fracture healing and risk of sepsis.

1.3.2 What is the functional outcome and does this compare with published outcomes?

2. MATERIALS AND METHODS

2.1 Ethics

This study has been approved by the Human Research Ethics committee of the University of the Witwatersrand. Clearance number is M060450

2.2 Study design

This study is a case series of patients who presented to the Johannesburg Hospital, Chris Hani Baragwanath Hospital, Helen Joseph Hospital and Sunninghill Hospital.

2.2.1 Inclusion criteria

The inclusion criteria were initially outlined as follows:-

a. Midshaft/diaphyseal fractures of the radius and/or ulna
b. Low-velocity gunshot wound <2cm diameter
c. Gunshot with wound less than 5cm diameter with no obvious contamination.
d. age >18years – able to consent
e. Isolated fracture – other fractures may influence rehabilitation
f. Patient is able to understand purpose of trial and consents to inclusion.

However, the expense of the implant for patients with simple fractures of either bone was not justifiable, and so point a) was modified to include only comminuted fractures of the midshaft of the radius and ulna.

It was also noted that other fractures did not seem to influence rehabilitation and so patients with multiple fractures were also included.

2.2.2 Exclusion criteria

Patients were excluded from the study if they met any of the following criteria:-

a) Fractures due to other causes
b) High velocity gunshot wounds with extensive soft tissue damage - wound diameter > 5cm
c) More than 2 weeks from fracture to surgery
d) Patient taking part in another study
e) Drug dependency
f) Patients not consenting

As mentioned above (2.2.1.), patients who had simple fractures that could be managed non-operatively or with plate and screws were excluded from the study. This decision was made by the orthopaedic consultant in charge of the unit treating the patient.

Figure 4: Low velocity gunshot wounds

2.2.3 Recruitment

The entire department of Orthopaedic surgery at University of Witwatersrand was briefed on the purpose of the study and the inclusion and exclusion criteria.

In addition posters were displayed in all casualties, operating theatres, wards and clinics used by the department, to remind doctors about the study.

A representative from Affordable Medical, the local distributors of the IM rod that was used in this study, notified the author whenever a rod system was ordered. The doctor ordering the rod was then contacted and patient eligibility was assessed.

On most occasions the insertion of an IM rod was the treatment of choice by the consulting surgeon irrespective of consent for the study. However on these occasions the patient was still consented for inclusion prior to enrollment.

When there was a choice of management, informed consent was obtained from the patient prior to inclusion.

At recruitment the patient completed a data sheet (Appendix A) and the fracture was classified according to the classification system of Gugala et al(4) (Appendix B)

2.2.4 Surgery

All surgery was performed under sterile conditions and regional or general anaesthesia in an operating theatre of either the Johannesburg Hospital, Chris Hani Baragwanath Hospital, Helen Joseph Hospital and Sunninghill Hospital.

The timing of surgery depended on the admitting doctor, the availability of theatre time and the general health status of the patient.

The surgery was performed by registrars and consultants in the department.

A data sheet was completed at the time of surgery by the operating surgeon (Appendix C).

2.2.5 Follow up

The initial protocol called for follow up of patients at 14 days post op, then 6 weeks, 3 months, 6 months and then longer if required. Due to the vast distances between hospitals, follow up forms (appendix D) and radiographic assessment forms (Appendix E) were placed in the orthopaedic outpatient department of each hospital. Registrars and consultants were requested to complete the forms when following up any study patients. Posters were placed in all consulting rooms reminding doctors to look out for these patients and complete the forms.

These forms and X-rays were then collected by the investigator and data was entered into a spreadsheet.

If forms were not available then information was taken from the doctors notes where applicable.

2.2.6 Final Assessment

Due to the nature of the injury and the population demographics, follow up at the clinic was always expected to be a problem. With this in mind it was decided to contact all patients who had been enrolled on the study and assess them at a minimum of 6 months post injury. This assessment consisted of the following:

2.2.6.1 Subjective

The patients were asked to complete a validated functional assessment questionnaire for the upper limb. This is known as the Disability of the Arm, Shoulder and Hand (DASH) score. (Appendix F).

2.2.6.2 Objective

All patients were assessed objectively regarding wound healing, fracture healing and range of movement of the injured arm (Appendix D).

2.2.6.3 Radiology

X-rays were taken of the injured forearm and assessed for fracture healing, alignment, shortening, loosening and sepsis.

2.3 Surgical Technique

All of the rods were inserted using the described technique.

All procedures were performed in the operating theatre under sterile conditions. Patients received either a general anaesthetic or a regional block.

All patients were given a dose of prophylactic antibiotics prior to inflation of the tourniquet.

The arm was placed on a radiolucent arm board attached to the table.

C-arm X-ray was positioned to allow ease of intra-operative screening.

The arm was prescrubbed with an antiseptic soap solution of choice to remove excessive debris from the arm and hand.

A tourniquet is positioned on the arm but not inflated until prior to the incision.

The arm is then prepared with an antiseptic surgical preparation in alcohol/betadine up to the tourniquet and draped with sterile drapes.

The tourniquet is inflated.

Debridement and irrigation of the bullet wounds is done according to necessity as decided by the surgeon intraoperatively.

An incision in made over the desired entry point. For the ulna this is over the olecranon, and for the radius this is on the dorsal surface of the distal radial metaphysis, radial to Lister’s tubercle.

The entry point is opened using an awl.

Sequential reamers are then inserted and the diameter and length of the rod are confirmed.

The appropriate size rod is inserted, ensuring the fracture is reduced. Care was taken to ensure the proximal and distal radio-ulnar joints are reduced. As noted in the discussion later it is advisable to ensure correct rotation of the distal radius when inserting the rod (supinated for proximal third fractures, neutral for middle third fractures and pronated for distal third fractures). (Figure 5)

The nail is inserted ensuring that the flange engages metaphyseal bone in the opposite segment (distal segment for ulna and proximal for radius).

The rod is then locked with a single screw through a jig on the insertion side of the nail.

The surgical wound is closed in layers according to surgeon preference.

The gunshot wounds are managed according to surgeon preference.

Most patients are splinted but again this varies from short arm volar splint to an above elbow backslab.

Figure 5: Inserting a rod into the radius

3. RESULTS

Twenty-one consecutive patients who received intramedullary rod fixation for a fractured radius and/or ulna were included in the study. The patients were collected between April 2006 and February 2008

3.1. Demographics (Table 1)

3.1.1. Age

The mean age of the patients was 35.1 years old (range 24-64 years)

3.1.2. Gender

Only one out of 21 patients was female, the remaining 20 were male

3.1.3. Occupation

The occupations of the injured included a broad spectrum from the unemployed to managing directors of companies. Those who were employed ranged from security officers to electricians.

3.1.4. Injured side vs. dominant hand

Right hand dominant individuals accounted for the majority of the cohort. However there was an even spread of injuries between the right and left forearms.

3.1.5. Previous injuries

None of the patients had previous injuries to the involved forearm

3.1.6. Other injuries

Other injuries sustained at the time of the forearm gunshot included gunshot wound to the spine, gunshot wound to the abdomen, a fractured femur and two patients with facial abrasions. One patient sustained an ipsilateral fracture of the lateral condyle of the humerus.

Table 1. Patient demographics and injuries sustained

No.	Age (yrs)	M/F	Occupation	*Dom. hand	Injured hand	Bones fractured	previous injury to limb	other injuries
1	30	M	taxi driver	R	L	Radius	no	no
2	44	M	Gardener	R	L	Ulna	no	no
3	30	M	dry cleaner	R	L	Both	no	no
4		M			R	Both	no	no
5	51	M	Welder	R	R	Radius	no	gsw spine T10 paraplegia
6	31	M	furniture removals	L	R	Radius	no	facial abrasions
7	33	M	Builder	R	L	Radius	no	no
8	30	M	security officer	R	R	Radius	no	no
9	39	M	Electrician	L	R	Radius		gsw abdomen
10	24	M	Labourer	R	R	Both	no	no
11	24	M		R	L	Ulna	no	no
12	29	M	Unemployed	R	L	Radius	no	no
13	24	M	van boy	R	L	Radius	no	facial lacerations
14	40	M			R	Ulna	no	no
15	64	M	security guard		L	Radius	no	no
16	38	F	MD of company		R	Radius	no	# femur
17	49	M	Driver	R	R	Radius	no	no
18	40	M	taxi driver	R	L	Radius	no	gsw R leg/# lat condyle of humerus
19	20	M	Unemployed	R	R	Radius	gsw humerus	no
20	28	M			L	Radius	gsw femur	no
21		M	machine operator	R	L	Ulna	no	no

*Dom. Hand = Dominant Hand

3.2. Gunshot wound classification (Table 2/ Appendix B)

3.2.1. Energy classification

All the patients were injured as members of the civilian population. Eight of the injured were able to positively identify the weapon as a low energy firearm. Two patients who sustained fractures of the forearm bones were excluded as they identified the weapons as high energy firearms. The remaining thirteen patients were included on the basis of suspected low-energy gunshot due to the appearance of the soft tissue injury and fracture configuration.

3.2.2. Vital structures injured

At the time of injury, seven patients exhibited neurological fallout of one forearm nerve. Three patients exhibited neurological compromise at final evaluation. Two involved the median nerve and one the radial nerve.

No significant vascular injuries were noted in the cohort.

3.2.3. Gunshot wound pattern (figure 4)

Sixteen patients exhibited penetrating gunshot wounds and the remaining five only had a single gunshot wound. In one of the patients the bullet was lying subcutaneously and removed at surgery.

3.2.4. Fracture Comminution (figure 3)

In order to be included, the fracture had to demonstrate comminution. According to the classification one fracture was graded as 25-50% comminution. The remaining fractures exhibited more than 50% comminution with 16 patients having more than 75% comminution.

3.2.5. Contamination

Unless there was obvious debris evident in the wounds, the patient was classified as moderately clean. However, four patients had a small amount of debris in the wound and were thus classified as moderately contaminated.

Table 2: Classification of gunshot injuries

No.	energy	vital structures	Wound	Fracture comminution	contamination
1	Suspected	Nil	Entrance only	50-75%	Clean
2	Confirmed	Neuropraxia	Penetrating	>75%	Clean
3	Confirmed	Nil	Penetrating	>75%	Clean
4	Suspected	Nil	Entrance only	>75%	Moderate
5	Confirmed	Nil	Penetrating	>75%	Clean
6	Suspected	Nil	Penetrating	>75%	Clean
7	Suspected	Nil	Penetrating	>75%	Clean
8	Confirmed	Nil	Penetrating	>75%	Clean
9	Confirmed	Neuropraxia	Penetrating	25-50%	Clean
10	Suspected	Nil	Entrance only	>75%	Moderate
11	Suspected	Neuropraxia	Penetrating	50-75%	Clean
12	Confirmed	Nil	Penetrating	>75%	Moderate
13	Suspected	Structural	Penetrating	>75%	Clean
14	Suspected	Nil	Penetrating	>75%	Clean
15	Suspected	Neuropraxia	Penetrating	>75%	Clean
16	Suspected	Nil	Penetrating	>75%	Clean
17	Suspected	Structural	Penetrating	>75%	Clean
18	Suspected	Nil	Entrance only	>75%	Clean
19	Confirmed	Nil	Penetrating	>75%	Moderate
20	Confirmed	Nil	Penetrating	>75%	Clean
21	Suspected	Structural	Penetrating	>75%	Clean

3.3. Surgical Details

The surgical technique described above is the general technique as recommended by the author. However, due to the experience of the surgeon, resources and difficulty of the individual fractures there was some variation in the surgery.

3.3.1. Time of surgery

Surgery was performed at the earliest convenience after the injury. This was dependant on the availability of theatre, the general health status of the patient and the experience of the registrar on call. The time period from injury to surgery ranged from 10 hours to 4 days.

3.3.2. Surgical team

The procedure was performed by both registrars and consultants. An assistant was used in 11/21 (52%) cases. This did not impact on the duration of surgery.

3.3.3. Duration of surgery

The mean duration of surgery for all the cases was 61.5 minutes (range 30-115 minutes). This includes cases where both the radius and ulna were fixed. Dividing the groups into patients with a radius fracture only, ulna fracture only and fixation of both bones provides the following times. The mean duration in patients who had only the radius fixed (n=14) was 51 minutes (range 30-90min). The group who had only ulna fixed (n=4) was 90 minutes (range 60-115min). The group that had both radius and ulna fixed (n=3) took an average of 68 min (range 60-85min).

3.3.4. Gunshot wound management

The management of the gunshot wounds was surgeon dependant and was primarily based on the perceived contamination of the wounds or whether there was structural damage necessitating exploration. As noted in appendix C the surgeons had the option of lavage only, debride only or debride and lavage of the wounds. The majority, 13/21 (62%), of the gunshot wounds were debrided and lavaged, while some 5/21 (24%) chose to only debride the wounds and a few 2/21 (9%) only lavaged the wounds.

Closure of the gunshot wounds was also left to the surgeon. Here again we also saw a variable pattern. The wounds were left open in 9/21 (43%) of cases, closed with sutures in 4/21 (19%), closed with staples 6/21 (29%) and one patient had delayed secondary closure of the wound.

3.3.5. Peri-operative antibiotics

All patients received pre-operative antibiotics and at least 24 hours post operative IV antibiotics. First generation cephalosporin, Kefzol, for 24 hours post-operatively was the antibiotic of choice. In 3/21 patients antibiotics were continued for more than 24 hours, and two patients received triple antibiotics, cephalosporin, gentamycin and metronidazole, for more than 24 hours at the surgeon’s discretion.

3.3.6. Post-operative immobilisation

No guidelines were given on post-operative immobilisation and the regimen varied between institutions and surgeons. The choice ranged from crepe bandage to above elbow slab and the duration varied from two to six weeks.

3.4. Assessment

Follow up data was collected on 15/21 (71%) of the patients prospectively enrolled in this study. The remainder of the patients were uncontactable or defaulted on further management in our clinics.

3.4.1. DASH

DASH questionnaires were completed by 10/15 (66%) patients. The score is calculated out of 100 with the lower score indicating better function. The median score was 7.5/100 (range was 3.3 to 84). The outlier score (84) was in one patient who had a painful, non-union. One patient, who did not complete the questionnaire due to difficulty understanding the questions, would have scored a high score as a result of a persistent median nerve paralysis.

3.4.2. Wound review

All of the surgical incisions healed without any other complications. All the gunshot wounds healed without any complications. There were no ongoing draining sinuses, suture granulomas or areas of granulation tissue exposed. This includes one patient who recovered well from a forearm fasciotomy. (Figures 6 and 7)

Figure 6 : Gunshot wound and rod insertion site two weeks postoperative

Figure 7: Gunshot wound and rod insertion site 6 months post operative

3.4.3. Range of Movement (figures 8-13)

Range of movement was measured at the elbow, wrist and forearm.

Elbow flexion returned to full in all but one patient who had flexion to 110 degrees. This patient had an isolated ulna injury.

Figure 8: Post operative flexion of the elbow

Two patients had less than full extension. The patient mentioned above had 40degree extension deficit and the other patient had 5 degree deficit. Both had isolated ulna gunshot wounds.

Figure 9: Post operative extension of the elbow

Wrist extension was only markedly decreased in two patients. One patient could only extend the wrist 30 degrees, but his DASH score was 3.4/100. The other patient, who had a painful non-union had limited wrist extension of 15 degrees.

Figure 10: Post operative wrist extension

Wrist flexion was limited to 30 and 40 degrees in two patients. One of whom was the same patient with marked limitation of wrist extension.

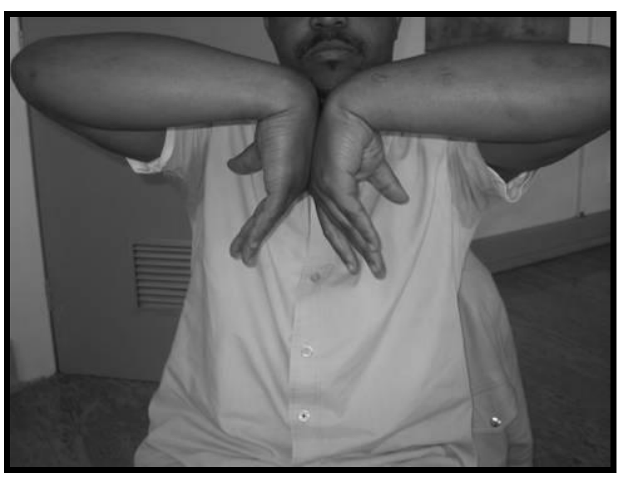

Figure 11: Post operative wrist flexion

Forearm rotation was measured as pronation and supination individually. An arc of 90 degrees between 45 degrees pronation and 45 degrees supination was considered acceptable. One patient had severe limitation of both supination and pronation with just 15 degrees of each; this was the same patient with a painful non-union. One patient had supination of 90degrees but could only pronate to neutral. He had DRUJ incongruity and this is discussed in more detail under complications.

Figure 12: Post operative pronation following fractured left radius and ulna

Figure 13: Post operative supination following fractured left radius and ulna

Table 3: Functional score and Range of movement

No.	DASH*	Elbow Flexion**	Elbow Extension**	Wrist Extension**	Wrist Flexion**	Pronation**	Supination**
1	3.3	140	0	80	80	90	90
2		110	40	50	60	60	70
3	8.3	140	0	90	90	45	45
4							
5							
6	6.7	160	0	80	80	90	80
7	3.4	140	0	30	60	60	60
8	3.3	150	0	90	80	80	50
9	84	135	0	15	40	15	15
10							
11							
12	5	140	0	80	80	70	70
13	23.3	140	0	90	90	80	90
14		140	0	80	80	40	90
15		140	0	70	80	0	90
16		140	0	70	30	70	40
17	33	140	0	80	80	90	30
18	17.5	130	0	90	90	90	70
19							
20							
21	elevated	130	-5	80	90	70	90

* Total score /100 – lower score indicates better function

** Measured in degrees

3.4.4. Radiography (Figure 14)

At a minimum follow up of six months, 14/21 patients were available for radiographic follow up. One other patient had his last follow up X-ray at 3 months post injury.

3.4.4.1. Fracture healing

Due to the comminuted nature of the fracture all the fractures healed by callus formation. As a result complete bridging of all four cortices, two on AP and two on lateral X-ray, was only seen in three patients (4 bones). The healed fractures ranged from bridging two cortices to all four. There was no significant difference in functional ability between the patients who had bridging of two, three or four cortices.

One patient had a painful, non-union at 6 months post-operatively. He had evidence of lucency around the rod suggesting some loosening. The locking screw remained firmly in situ and did not appear loose.

3.4.4.2. Alignment

The alignment of the main proximal and distal fragments was well maintained. Two patients who had slight malalignment from the initial reduction maintained their position.

One patient who sustained a distal radius fracture deviated ulnarly. This is the same patient who had the DRUJ incongruity.

3.4.4.3. Length

One patient with a distal radius fracture had shortening at the fracture site and developed DRUJ instability. The fracture healed well with good callus formation. He required an ulna shortening osteotomy and remained with a pronation deficit.

The remainder of the patients maintained the length of the fractured bone and congruity of the proximal and distal radio-ulnar joints.

This included one patient who had a proximal radio-ulnar joint dislocation similar to a type 1 Monteggia fracture. The radial head was reduced at surgery and at 3 months follow up the radial head was still reduced.

Figure 14: X-ray at six months of patient in figures 8-13

Table 4: Final assessment X-ray findings

No.	time post op	Bones Fractured	alignment AP	alignment lat	Shortening	screw position	fracture line*	callus†
1	12/12	Radius	straight	Straight	nil	intact	5	5
2	3/12	Ulna		Straight	nil	intact		3
3	12/12	Ulna	Straight	Straight	nil	intact	5	6
			Ulna	straight	nil	intact		
	12/12	Radius	deviation				5	6
4		Both						
5		Radius						
			Straight	straight	nil	intact		
6	9/12	Radius					5	4
7	6/12	Radius	Straight	straight	nil	intact	5	5
8	6/12	Radius	Straight	straight	nil	intact	4	3
9	6/12	Radius	Straight	straight	nil	intact	0	1
10		Both						
11		Ulna						
12	12/12	Radius	Straight	straight	nil	intact	4	3
13	12/12	Radius	Straight	straight	nil	intact	5	6
14	12/12	Ulna	Straight	straight	nil	intact	3	3
15	6/12	Radius	Straight	straight	5mm	intact	1	4
16	6/12	Radius	Straight	straight	nil	intact	3	3
17	12/12	Radius	Straight	straight	nil	intact	5	6
		Radius	Radial	straight	nil	intact		
18	12/12		deviation.				4	5
19		Radius						
20		Radius						
21	14/12	Ulna	straight	straight	nil	intact	5	5

Key: *Fracture line
- 0 – fracture line clearly visible
- 1 – fracture line hazy
- 2 – partially obliterated 1 plane
- 3 - partially obliterated 2 planes
- 4 – totally obliterated 1 plane
- 5 – totally obliterated 2 planes

†Bridging callus
- 0 – callus absent
- 1 – hazy around fracture site
- 2 – bridging callus 1 cortex
- 3 – bridging callus 2 cortices
- 4 – bridging callus 3 cortices
- 5 – bridging callus 4 cortices
- 6 – complete union

3.5. Complications

3.5.1. Gunshot related

Seven patients reported some neurological fallout at the time of injury and 3 remained with documented neurological compromise. The most commonly injured nerve was the median nerve.

One patient demonstrated an inability to extend the thumb. This was initially thought to have been due to injury to the extensor pollicis longus (EPL) tendon at insertion of the rod. The patient was explored in theatre but the EPL tendon was found to be intact. The lack of movement was therefore thought to result from an injury to the EPL branch of radial nerve.

Two patients had ongoing median nerve symptoms, primarily with loss of sensation over the median distribution of the hand and inconsistent weakness of the thenar muscles.

One patient sustained a laceration of the extensor indicis tendon to the middle finger. This was repaired at the time of surgery and the patient recovered fully.

3.5.2. Surgery related

Specific complications that were sought related to the radius and ulna rods individually.

Insertion of the radius rod may result in damage to the EPL tendon as described in the technique section. This was not noted in any patients.

Insertion of the ulna nail requires careful positioning of the entry point to prevent radial or ulna deviation at the fracture site. The entry point was adequately placed in all cases and no proximal locking screws entered into the olecranon fossa.
Two patients reported dorsal wrist pain at the insertion site due to a rod that was too proud. The rods were removed and the pain resolved.

3.5.3. Healing related

One patient required a fasciotomy for suspected compartment syndrome of the forearm. A delayed primary closure was done and his wounds healed well. He had some slight residual weakness of the forearm, but the fracture united with no sepsis.
The one patient, on whom we had complete follow up, with both radius and ulna fractures developed a synostosis at the fracture site. He did have decreased rotation of the forearm, but his subjective functional evaluation was essentially normal (DASH 8.3/100).
One patient developed a non-union at the fracture site. (Figure 15)

Figure 15: Non union at fracture site

3.5.4. Implant related

There was only one case of implant failure. One patient as previously mentioned with a DRUJ disruption. The DRUJ was incompletely reduced at the time of the initial surgery and this shortened further after the nail was inserted. An ulna shortening osteotomy was performed and he regained good wrist movement, but had a pronation deficit.

Table 5: Summary of complications

No.	Complication	Resolved
1	insertion site pain	removal of nail
2		
3	radioulnar synostosis	
4		
5		
6		
7		
8		
9	Nonunion	
10		
11		
12		
13	inability to extend thumb	Exploration EPL
14		
15	DRUJ - ulnar shortening	ulnar shortening osteotomy, median neuropraxia
16	Insertion site pain	
17		
18	fasciotomy	healed well
19		
20		
21	median nerve palsy	generalised weakness of the hand

4. DISCUSSION

4.1. Current Literature

There is a paucity of literature describing the results of management of gunshot wounds to the radius and ulna. Extensive review of the literature reveals a small number of case series that review the outcomes of the management of these fractures.(16, 22, 23) The consensus among these papers is that undisplaced fractures can be safely treated by plaster immobilisation, while displaced fractures should be reduced and stabilised by open reduction internal fixation.

Intramedullary forearm nailing for any fracture of the forearm was highlighted by Street in 1985(24). He proposed closed nailing with the advantages being improved healing through greater stability and better circulation of the intact periosteum, smaller incisions with less surgical trauma and better cosmesis. His paper was not widely accepted for standard fracture management as the complications and difficulty of nail insertion precluded daily use. Also it is well proven that rigid fixation, of radius and ulna fractures, is the gold standard.

With time the quality and availability of new intramedullary rods has improved and intramedullary nailing of the radius and ulna has become a much more accepted procedure. Although still not universally accepted for simple, low energy fractures. New literature describing the management of forearm fractures now include intramedullary nailing as one of the options of stabilising a displaced, comminuted fracture(25). However, even this suggestion has no published reference.

The potential benefits of intramedullary nail insertion for gunshots are less disruption of the fracture site and surrounding compromised soft tissue and easier alignment of the bone ends to an anatomical rod.

This report is the first report detailing the outcomes of intramedullary nailing specific for gunshot wounds.

4.2. Demographics

The demographic spread of our cohort represents the population group at risk for this type of injury. This population group is the young to middle aged working male. For many families this person is the bread winner and so a reliable stable fixation of fractures is required to allow the patient to return to work as soon as possible.

Fortunately for our group there was a low incidence of other associated injuries with most patients presenting with isolated fractures. Although patients with multiple fractures and injuries were considered for exclusion, the other injuries did not appear to influence the outcome of the forearm fractures.

The one patient who developed a non-union, also sustained a gunshot wound to the abdomen and although there was no overt evidence of sepsis, it is possible that a bacteraemia from the gut may have seeded to the fracture site/implant and resulted in a low grade sepsis and thus non-union. The patient refused further surgery so we were unable to confirm this on tissue culture.

There was no link between the side of the injury and the dominant hand.

4.3. Significance of Classification of injury

Classifications are designed in order to standardize management across a spectrum of related but different conditions. Often a classification may predict the outcome of a disease or injury, or it may predict the best form of management or used only as a research tool. The choice of Gugala et al's classification of civilian gunshot injuries (4) was made simply to standardize the patients to a recognised classification system. This is by no means the only classification available. However, this classification has proved extremely useful in further defining which patients will be suitable for intramedullary nailing.

Intramedullary nailing can be considered for any patient who has sustained a low energy confirmed or suspected injury with > 25% comminution as defined by the classification.

The value of the wound classification i.e. whether the bullet has grazed the soft tissue or there is an entrance only, does not seem to influence the management of forearm injuries. In order to cause a fracture the bullet must penetrate at least one skin surface. If the bullet is retained this may indicate too little kinetic energy to exit and thus a very low energy injury, or the bullet has hit the bone and transferred a very high amount of energy causing it to stop in the soft tissues. Management is then guided by the fracture pattern and soft tissue status.

The documentation of contamination level of the wound as clean, moderate contamination or marked contamination is user specific. One is also never completely sure of what debris the bullet took into the wound. This cohort consisted only of patients with clean or moderately contaminated wounds and there was no difference in infection rates or wound healing. Perhaps one may argue that patients with clean wounds do not need prophylactic antibiotics, which all of the patients in this series did receive. The low morbidity of antibiotics coupled with the admission for surgery makes 24 hours of prophylactic antibiotics almost a necessity.

The documentation of the soft tissue injury is vital to determine the final outcome. Severe soft tissue injury with vascular and bowel injury may have serious consequences. However, it is the lesser neurological and musculotendinous injuries that may be the most debilitating. Despite adequate bone treatment and fixation a persistent neurological injury may seriously affect the functional quality, as evidenced by our patients with persistent median nerve injury (particularly patient 21).

4.4. Evaluation of surgical technique

The technique of insertion of forearm rods has been refined with new anatomically designed implants.

The level of surgical expertise of the operating surgeon varied from experienced consultant orthopaedic surgeons to junior registrars without senior support. The uniformly good results are not related to the level of training of the surgeon. Approximately half of the procedures were performed without an assistant, again highlighting the ease of insertion. The use of an assistant is recommended though to assist with the difficult reductions and to position the forearm in the correct amount of rotation to allow the surgeon to insert the rod.

As with any new procedure there is a learning curve and the longer operating times were indicative of this. Once the surgeon had become confident with the procedure, operating time tended to decrease towards the mean time. The potential benefit of this procedure is the necessity, most of the time, to not open the fracture site. The closed reduction of the fracture is usually the rate limiting step of the procedure. This is in contrast to other rods that require freehand locking of the end opposite to insertion. The freehand locking is often through a small hole in the nail and requires soft tissue dissection, prolonged X-ray screening and some skill.

The value of not inserting a freehand locking screw is also noted in relation to decreased radiation exposure.

4.5. Evaluation of results

4.5.1. Subjective function

The DASH score was chosen as a subjective measure of outcome for the study. It is a validated, generalised upper limb functional scoring system. It was a useful tool in this project but was not intended to be a primary outcome measure. As evidenced by patients with ongoing neurological injury, the fracture may have healed but then soft tissue injury was the limitation to function and thus resulted in a high score.

The DASH was useful in two of the patients. The patient who developed the painful non-union had a very high DASH score indicating that if there is significant disability from poor fracture outcome it will be revealed using DASH score.

The other case is the patient with the radio-ulnar synostosis who had limited pronation and supination, but an arc of movement of 90degrees. His DASH score returned to almost zero. This highlights the amount of compensation within the upper limb provided that the fractures have united.

None of the other studies published on the management of forearm gunshot wounds have used a subjective scoring system, so it is not possible to compare these results with other studies.

4.5.2. Objective evaluation

Wound healing and functional range of movement was evaluated.

4.5.2.1. Wound Healing

Wound healing was divided for evaluation in two categories. These were the surgical wounds and the gunshot wounds. One patient required forearm fasciotomy for suspected compartment syndrome

4.5.2.1.1. Surgical wounds

All the surgical incision sites healed without complications as should be expected.

4.5.2.1.2. Gunshot wounds

There was no standard management of the gunshot wounds. Some of the wounds were debrided and closed, while others were only washed out and left open or any combination of these two. Despite this variability there was no evidence of increased sepsis in any group. All patients did receive prophylactic IV antibiotics. Drawing a conclusion from this probably shows that prophylactic antibiotics are the most important element of sepsis prevention. However, there is no control group to compare this to.

4.5.2.1.3. Fasciotomy

One patient required a fasciotomy for suspected compartment syndrome. At final evaluation the wounds had healed well, with no evidence of sepsis. The fracture had also united and function had returned.

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4.5.2.2. Functional Range of movement

As discussed in the introduction the forearm is a complex joint. Inadequate reduction and healing of these complex fractures can lead to limitation of movement. This may occur at the elbow with incongruence of the proximal radio-ulnar joint or damage to the triceps tendon with insertion of the ulna rod. Two patients had some loss of movement at the elbow. The one patient had a dislocated radial head and fractured ulna at the time of injury. Insertion of an ulna rod reduced the fracture and restored the length of the bone. The radial head was reduced at the time of surgery. Post-op X-rays confirmed reduction and follow up X-ray at 3 months post injury showed good fracture healing and maintained reduction of the proximal radio-ulnar joint. However at this time the patient had a 40 degree fixed flexion. Unfortunately he did not return for further follow up. The second patient had a five degree fixed flexion deformity at the elbow but had no functional limitations.

Inadequate reduction of the DRUJ can lead to abnormal wrist and forearm movement. One patient was diagnosed with an incongruent DRUJ at the time of his injury. Although reduction was attempted at the time of surgery it was incomplete. This patient's radius collapsed further and although the fracture united he required a distal ulna shortening osteotomy. This case highlights one of the potential weaknesses of this procedure. Patients with distal radius fractures extending into the metaphysis with DRUJ incongruity may not be ideal candidates for an intramedullary rod. The rod sizes increase in increments of 20mm and this may limit the possibility of finding an exact length. A slightly shorter rod may be well tolerated in patients with intact proximal and distal radio-ulna joints. If there is loss of the soft tissue restraints, this slight lack of support and the potential for shortening if not well impacted, may result in progression of the incongruity. In addition, the wide distal radial metaphysis does not offer cortical support for the rod, predisposing to angular deformity.

A 90 degree arc of rotation of the forearm is considered functional. The majority of our patients had at least this amount of rotation. It is important to re-emphasize that, particularly when inserting the radial rod, to ensure the correct rotation of the distal fragment relative to the proximal one as highlighted in the techniques section. This could possibly have improved some of our results.

4.5.3. Radiography

4.5.3.1. Fracture healing

An attempt was made to assess the radiographic outcome based on fracture union. Although it would be nice to see well restored cortices and bridging across all “four” cortices this was not the case. The AP X-rays only show the radial and ulnar cortices, while the lateral shows the anterior and posterior ones. The radiographic healing has thus been based on these four cortices. This is somewhat flawed as bone healing occurs in 360 degrees around the rod. The healing is also callus healing which does not necessarily result in restoration of the complete cortex. However, all patients had a solid bridge of bone between the proximal and distal fragment. The more comminuted the fracture the less uniform this bone bridge was but all except one patient had at least two cortices bridged. Three patients had complete union of the entire bone.

One patient who had a fracture of both the radius and ulna developed a radio-ulnar synostosis. Clinically he retained 90 degrees of rotation from 45 degrees supination to 45 degrees pronation. He was subjectively happy with his range of movement. Although only one patient with both bone fractured was followed up to union, it would seem that these patients may be predisposed to developing radioulnar synostosis. A soft tissue connection between the fracture of the radius and ulna due to the bullet tract may allow for bone ingrowth.

This observation may not be relevant only in patients who receive an IM rod.

4.5.3.2. Alignment

The true immediate benefit to this procedure is the restoration of the coronal and sagittal alignment. The cortical fit of the rod ensures almost guaranteed longitudinal alignment. Distal radial fractures where there is flaring of the metaphyseal bone is the one instance where perfect alignment is not guaranteed, but acceptable alignment can be achieved. This alignment was maintained until union.

4.6. Comparison of results with published data

There is a distinct paucity of published data concerning the management of gunshot wound to the radius and ulna(16, 22, 23, 25, 26). Further review of these papers reveals 2 case series(16, 22), one case report(23) and an overview of the general management of these injuries(25, 26).

Elstrom et al(16) published the first paper looking specifically at the outcomes of the fractures due to gunshot wounds of the forearm. They reviewed 29 patients who presented over a 3 ½ year period who presented to their institution. Twenty-one (72%) patients were followed up more than 6 months, an additional five were followed up until 6 weeks and the remaining 3 were lost to follow up. Final assessment of the patients included range of motion, assessment of motor and sensory function of the hand and X-rays. Eighteen patients (62%) completed this final evaluation.

Their soft tissue management also varied with most wounds left open after debridement, and all patients receiving IV and oral antibiotics for up to 8 days. They reported no early wound infections and no late osteomyelitis in the 21 patients who returned for late follow-up.

Initial management of the fractures was an axilla to palm cast. Cases that were markedly displaced had Steinman pins inserted into the 1st metacarpal and the proximal ulna and these were incorporated into the cast. This was to prevent shortening and rotation. The displaced fractures tended to have delayed union when treated this way and subsequent patients were then treated by open reduction internal fixation (ORIF) seven to fourteen days after the injury. Severely comminuted fractures were debrided with the devitalized fragments discarded and the void filled with autogenous iliac crest bone graft.

The results of their patients who sustained displaced comminuted fractures, the basis of our study, are as follows. Fifteen patients with displaced comminuted fractures were treated by closed methods i.e. cast alone (6 patients) or cast and pins (9 patients). The authors state that “the results in these fifteen patients were, for the most part, unsatisfactory because of malunion, delayed union or loss of function. Seventy-five percent of those treated by cast alone had malunion and significant loss of rotation or wrist movement. One-third (3/9) of the patients treated with cast and pins malunited, with more than 50% loss of rotation.”

Their results in these patients improved with ORIF. Six patients were treated this way and the results were “far superior”. They reported no instances of delayed union or malunion. Only one patient had significantly reduced rotation of the forearm.

Satisfactory use of the forearm was regained in 8 weeks in the ORIF group, and 4 months in the plaster cast group.

This study clearly shows that internal fixation of displaced comminuted fractures due to gunshot wounds, is safe and superior to cast management.

Lenihan et al(22) reviewed 37 extra-articular gunshot wounds of the forearm, 14 were displaced. Eight of the fourteen were treated with cast immobilisation and the remaining six were treated by ORIF. Six patients had poor clinical results and five of these were treated by cast immobilisation. Their recommendation was that displaced fractures of the radius and ulna were best treated by ORIF.

Wu (23) published a case report of a combined fracture of the radius and ulna treated by debridement and external fixation. This patient also had a defect in the olecranon treated by iliac crest autograft.

The remaining articles Hahn et al (26) and Wilson (25) discuss the generalised management of the soft tissues and bone. They refer to the previous mentioned articles that ORIF is recommended for displaced comminuted fractures, but also mention that intramedullary nailing can be considered. This recommendation is not referenced in either article and may be their expert opinion.

In comparison, in the present study, 15/21 (71%) patients, only with displaced comminuted fractures, were followed up. The subjective, DASH, evaluation shows a high satisfaction in patients without associated neurological compromise. Objectively, our wound healing and range of movement are at least comparable if not better. Radiographically, all but one patient united within the six months post operatively.

The one patient who had a non-union may have had a low grade sepsis and he was at high risk for sepsis with associated abdominal trauma. However, it is impossible to directly compare data from two separate trials and comment on statistical significance as there are too many variables that differ between the two groups.

When comparing the data however, the results of ORIF to IM nailing are similar. The potential benefit of the IM nailing is the preservation of autologous bone in the area, negating the need to harvest new autologous bone form a distant site e.g. the iliac crest. This has the potential for increased morbidity.

Although Elstrom et al (16) performed delayed ORIF, it would seem that it is now possible to perform an early ORIF.

This study confirms that early IM nailing of these fractures is safe and recommended.

4.7. Limitations of technique

As with any surgical technique there are always limitations. These can be divided into limitation of indication, limitation in technique and costs.

4.7.1. Limitation of indication

The IM rod performed best in midshaft diaphyseal injuries. These rods are not recommended for fractures extending into the distal radial metaphysis or the olecranon. Care should also be taken in distal ulna fractures and proximal radius fractures. The large variation between lengths of the rod may result in over distraction of the fracture site or a prominent rod at the insertion, if too long, or inadequate purchase of the rod in the opposite metaphysis if too short.

4.7.2. Limitation in technique

Although the technique is relatively simple, it is important to ensure that the direction of the entry point is correct. Patients with wide medullary cavities or fractures close to the insertion site may tend to angulate slightly. It is always recommended to be familiar with the implant that is being inserted and if necessary having a representative of the company present to advise.

4.7.3. Costs

The greatest limitation of this procedure is the cost of the implant. The rods retail at approximately R5000.00 each, compared with a plate and screws which costs approximately R200.00. This may prohibit the generalised use of this implant. Until a randomised control trial is completed comparing the outcome of patients with rods versus plating, and also the cost implications with regard to theatre time and complications, it will be difficult to justify the widespread implementation of this implant.

4.8. Limitations of study

This study is limited in that it is a case series and does not compare IM nailing directly to ORIF. This does limit the conclusion that can be drawn. However, the patient population is too small to obtain adequate numbers, which would provide statistical significance.

Only 15/21 patients were available for follow up at least three months post operatively, with 14/21 being finally assessed at union. These numbers are in line with the follow up obtained in other similar studies and may reflect the patient population. This is despite education of the patient, treating doctors and direct contact with the patients.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Primary research question

5.1.1. Implant design and function

The implant design is user friendly and assists in the reduction of the fracture. If used in patients with diaphyseal fractures with cortical contact, it reduces the fracture anatomically in the coronal and sagittal planes. Care should be taken with fractures extending into the metaphysis.

The rod functioned well in maintaining the reduction and there were no cases of implant breakage or failure.

5.1.2. Fracture healing

The IM nail did not result in delayed healing. The one non-union is within the normal range for this type of injury. All remaining fractures healed satisfactorily.

5.1.3. Sepsis

There was only one case with suspected sepsis in a patient at higher risk due to abdominal trauma. There was no other documented case of infection.

Intramedullary nailing of the radius and ulna does not increase sepsis rates in these patients.

5.2. Secondary research question

A subjective return to function is dependant on the soft tissue injuries sustained at the time of the gunshot. Documented nerve injuries have a reported poorer outcome. This was confirmed in this series. Patients without neurologic injury made excellent recovery to almost full level of function. No other study has evaluated subjective patient function so this cannot be compared to other series.

Objectively, almost all the patients with IM rods regained full motion of the elbow and wrist. A small deficit in rotation can be expected but almost all patients regained a functional range of rotation.

Inserting an IM rod into patients with displaced comminuted gunshot wounds of the radius and/or ulna does not compromise functional outcome.

5.3. Recommendations

Intramedullary nailing for low-velocity gunshot wounds of the radius and ulna is a safe technique. It is recommended particularly in patients who have displaced and comminuted fractures.

Appendix A

Appendix A: GSW radius/ulna study

Demographics

Last name: ______________________ First Name: ___________________

Patient No.: _____________________ Study ID: gswf0_/________

Date of Birth (dd/mm/yy): ___/___/_____ Gender: **O** Male **O** Female
Age (yrs):________

Date of Admission(dd/mm/yy)): ___/___/_____ Time of injury:___h___

Date of surgery(dd/mm/yy)): ___/___/_____ Time of surgery:___h___
Delay between injury and surgery: ___days _____hours

Occupation: _______________________

Dominant Hand: **O** Left **O** Right

Injured forearm: **O** Left **O** Right

Previous injury to upper limb: **O** Yes **O** No
If yes describe injury:

____
____
____
____

Other injuries: **O** Yes **O** No

____
____
____
____
____
____

Details captured by:______________________________

Appendix B

Appendix B: GSW radius/ulna study

Study ID:____________

Injury classification(4)

Patient letters:__________

Patient number:_______________

Energy	
Low energy – confirmed	LE-C
High energy – confirmed	HE-C
Low energy – suspected	LE-S
High energy – suspected	HE-S
Vital structures (add details below as appropriate)	
No vital structure injured	V=0
Functional damage(neuropraxia)	V=1
Structural damage of small neurovascular structures	V=2
Injury to viscera, major vessels (prox to and including brachial and popliteal artery), or central nervous system	V=3
Wound	
Non penetrating (grazing or blast)	W=1
Penetrating (non-exiting)	W=2
Penetrating (in and out)	W=3
Fracture	
No Boney fracture or # not requiring stabilization	F=0
Extra-articular	
Comminution <25%	EF=1
Comminution 25-50%	EF=2
Comminution 50-75%	EF=3
Comminution >75% or segmental defect	EF=4
Contamination	
Relatively clean wound	C=1
Moderately contaminated wound (clothing debris)	C=2
Grossly contaminated wound (viscus/bowel content)	C=3

Classification = LE-__; V__; W__; EF__; C__

Vital structures injured:

O radial nerve **O** median nerve **O** ulna nerve

O posterior interosseous nerve **O** anterior interosseous nerve

O radial artery **O** ulna artery

O other ___________________________________

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Checked by investigator: ______________________________________

Appendix C

Appendix C: GSW forearm

Study ID: ____________

Surgical details

Patient letters: _______________
Patient number: _______________

Date of surgery (dd/mm/yy) ___/___/_____
Time of surgery (start): ___h___
Time of surgery (end): ___h___
Duration: ______minutes

Surgeon: ____________________
Assistant: ______________________

Injured arm: **O** Left **O** Right

Bones fixed: **O** radius **O** ulna **O** both

Entry point: **O** standard **O** other_________________________________

Rod length: ________mm **Rod Diameter**: _____mm
Locking screw: **O** standard **O** other ________________________

Nail wound closure: **O** staples **O subcuticular** sutures
O interrupted sutures

Gunshot wound management: **O** lavage only
O debridement only
O lavage and Debridement
O wound left open
O wound closed – sutures
O wound closed – staples
O other ______________________________

Gunshot wound dressing: **O** dry
O paraffin gauze
O saline soaked swabs
O suction dressing
O other ______________________________

Tourniquet: **O** No **O** yes time: _______minutes
Preoperative antibiotics: **O** No **O** yes name__________ dose____
Postoperative antibiotics: **O** No **O** yes name__________ dose____
Duration___________________

Checked by investigator: __________________

Appendix D

Appendix D:GSW radius/ulna

Study ID:____________

Follow up examination

Patient letters:__________
Patient number:_______________

Date(dd/mm/yy): ___/___/_____ **O** post op **O** 6/52 **O** 3/12 **O** 6/12 **O** 12/12
Other:_______________

Functional status: DASH score ________ (attach questionnaire please)

Has patient returned to work: **O** no **O** yes
If yes – date started: light duty ___/___/_____ full duty ___/___/_____

Clinical exam:
Wounds:

Site	Clean	Healing		Breakdown				Sepsis
		Epithelialising	Granulating	<25%	25-50%	50-75%	>75%	
Surgical incision								
GSW								

For each gsw please fill in site and use a separate line

Tenderness at fracture site: **O** no **O** yes

Range of movement:

Joint	Flexion	Extension	pronation	supination
Elbow				
Wrist				

Vascular status:
O normal **O** decreased perfusion – comment_________________________

Neurological exam:

	Sensation(n/decr/absent)	Motor (power /5)	EMG (yes/no)
Median nerve			
Ulna nerve			
Radial nerve			
Post interosseous			
Other__________			

Checked by investigator:_____________________________________

Appendix E

Appendix E: GSW forearm

Study ID: ____________

Patient initials: _______________

Patient number: _______________

Radiographic evaluation (1/2)

Date of surgery (dd/mm/yy): ___/___/____

Reviewer: _______________________

Reviewed by: **O** initial surgeon **O** study researcher **O** other Dr: _________________

Date of review (dd/mm/yy): ___/___/___

Reviewed at: **O** 3/52 **O** 6/52 **O** 12/52 **O** 18/52 **O** 6/12 **O** 9/12 **O** 1 year **O** Other: ____________

Bone involved: **O** radius **O** ulna **O** both

Side: **O** left **O** right

Fracture comminution:

radius	ulna
O <25%	**O** <25%
O 25-50%	**O** 25-50%
O 50-75%	**O** 50-75%
O >75% or segmental	**O** >75% or segmental

Alignment in AP:

radius	ulna
O straight	**O** straight
O radial deviation: __degree	**O** radial deviation: __degree
O ulna deviation: __degree	**O** ulna deviation: __degree

Alignment in lateral:

radius	ulna
O straight	**O** straight
O ant angulation: __degree	**O** ant angulation: __degree
O post angulation: __degree	**O** post angulation: __degree

Distraction: **O** none **O** radius - ____mm **O** ulna - ____mm

Screws:

radius	ulna
O in place	**O** in place
O pulled out	**O** pulled out
O broken	**O** broken

Study ID: __________

Radiographic evaluation (2/2)

Patient initials: _____________
Patient number: ____________

Fracture line: radius	ulna
O visible	**O** visible
O hazy	**O** hazy
O partially obliterated in 1 plane	**O** partially obliterated in 1 plane
O partially obliterated in 2 planes	**O** partially obliterated in 2 planes
O totally obliterated in 1 plane	**O** totally obliterated in 1 plane
O totally obliterated in 2 planes	**O** totally obliterated in 2 planes

Callus: radius	ulna
O absent	**O** absent
O hazy around fracture	**O** hazy around fracture
O bridging callus – 1 cortex	**O** bridging callus – 1 cortex
O bridging callus – 2 cortices	**O** bridging callus – 2 cortices
O bridging callus – 3 cortices	**O** bridging callus – 3 cortices
O bridging callus – all around	**O** bridging callus – all around
O solid union	**O** solid union

Notes
____
____
____
____
____

Checked by investigator: _______________________________________

Appendix F: DASH score

DISABILITIES OF THE ARM, SHOULDER AND HAND

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Write.	1	2	3	4	5
3. Turn a key.	1	2	3	4	5
4. Prepare a meal.	1	2	3	4	5
5. Push open a heavy door.	1	2	3	4	5
6. Place an object on a shelf above your head.	1	2	3	4	5
7. Do heavy household chores (e.g., wash walls, wash floors).	1	2	3	4	5
8. Garden or do yard work.	1	2	3	4	5
9. Make a bed.	1	2	3	4	5
10. Carry a shopping bag or briefcase.	1	2	3	4	5
11. Carry a heavy object (over 10 lbs).	1	2	3	4	5
12. Change a lightbulb overhead.	1	2	3	4	5
13. Wash or blow dry your hair.	1	2	3	4	5
14. Wash your back.	1	2	3	4	5
15. Put on a pullover sweater.	1	2	3	4	5
16. Use a knife to cut food.	1	2	3	4	5
17. Recreational activities which require little effort (e.g., cardplaying, knitting, etc.).	1	2	3	4	5
18. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5
19. Recreational activities in which you move your arm freely (e.g., playing frisbee, badminton, etc.).	1	2	3	4	5
20. Manage transportation needs (getting from one place to another).	1	2	3	4	5
21. Sexual activities.	1	2	3	4	5

DISABILITIES OF THE ARM, SHOULDER AND HAND

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
22. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? *(circle number)*	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? *(circle number)*	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*

	NONE	MILD	MODERATE	SEVERE	EXTREME
24. Arm, shoulder or hand pain.	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. Stiffness in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. *(circle number)*	1	2	3	4	5

DASH DISABILITY/SYMPTOM SCORE = $\left[\left(\frac{\text{sum of n responses}}{n}\right) - 1\right] \times 25$, where n is equal to the number of completed responses.

A DASH score may not be calculated if there are greater than 3 missing items.

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:______________________________

❒ I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*.
If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:______________________________

❑ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may not be calculated if there are any missing items.

INSTITUTE FOR WORK & HEALTH
INSTITUT DE RECHERCHE SUR LE TRAVAIL ET LA SANTÉ

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Appendix G: Ethics Clearance

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Gelbart/Aden

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER M060450**
PROJECT	Evaluation of Intramedullary Nailing in Low-Velocity Gunshot Wounds of the Radius and Ulna
INVESTIGATORS	Drs BR/AA Gelbart/Aden
DEPARTMENT	Orthopaedic Surgery
DATE CONSIDERED	06.05.05
DECISION OF THE COMMITTEE*	APRPOVED UNCONDITIONALLY

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 06.07.20 **CHAIRPERSON** ......M Vorster...... pp (Professor A Dhai)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : Dr AA Aden

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

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